Out-of-Plane Effects in Ocean Acoustics

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LONG-TERM GOALS

The focus of my current research is to develop improved models of signal and noise propagation in complex, three-dimensional environments.

OBJECTIVES

In recent years tremendous progress has been made in modeling both the ocean environment and its effects on sound. Global models of the 4D (space-time) oceanography are produced both regularly and frequently. They are also readily available through FNMOC Reachback Support. In fact, rather than just a deterministic forecast, the oceanographic models routinely provide ensemble forecasts representing a 'fuzzy' ocean, i.e. a distribution of possible realizations.

Interestingly, the sound models that propagate through such fields have really not kept up. Three-dimensional propagation modeling has, of course, been a research topic of interest for many decades. However, it has never really become a mainstream activity, partly because it used to be too time-consuming, partly because the environmental information was not available.

The community has now clearly recognized that the time is right to take a step up in the modeling capability and do fully three-dimensional modeling using ensemble forecasts of the ocean structure. The goal of this research is to do exactly that, leveraging the BELLHOP3D Gaussian beam tracing code. Further enhancements will be made to BELLHOP3D; however, a particular focus will be the assessment of 3D effects in various upcoming experiments.

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APPROACH

We will be investigating other 3D approaches; however, we anticipate that BELLHOP3D will be the main tool for this work. BELLHOP3D is an extension of the widely used BELLHOP model. Separately we have been working with FOR3D (3D parabolic equation model), which will be used to provide independent benchmark solutions.

We are also pursuing experimental opportunities to both validate the models and clarify under what circumstances 3D effects are important. In the near term we are pursuing collaborations with the NATO Center for Marine Research and Exploration (formerly NURC). In the longer term we are making plans with respect to the ONR OA Shelfbreak/ Slope/Canyon Field Experiment.

WORK COMPLETED

Recent work has focused on benchmarking and optimizing BELLHOP3D. However, within the scope of this work, we have also continued maintenance of the Ocean Acoustics Library. This continues to be an important resource for the community and we've recently added a number of things including the PocketBook of Underwater Acoustics from JASCO, a Matlab version of KRAKEN from Brian Dushaw, and a new front page discussing ambient noise in the Philippines Sea. We have also added another 3D ray tracing model (Under Sea Modeling Library/ Sean Reilly/URI) and a 2D beam tracing code (TRACEO/Orlando Rodriguez and Emanuel Ey/U. Algarve).

Additional thrusts of this work are to a) examine 3D effects for noise modeling and b) develop more sophisticated approaches to modeling ocean dynamics. A particularly important application is for underwater acoustic communications and we have co-organized an Underwater Communications Conference and Workshop which proceedings in the Journal of Oceanic Engineering will fully document that effort.

RESULTS

A sample oceanographic field was downloaded from the HyCom site for a particular day in 2011 (Fig. 1). The site is just to the east of Taiwan. Bathymetry was taken from the ETOPO1 site (Fig. 2). Both these databases provide global coverage.

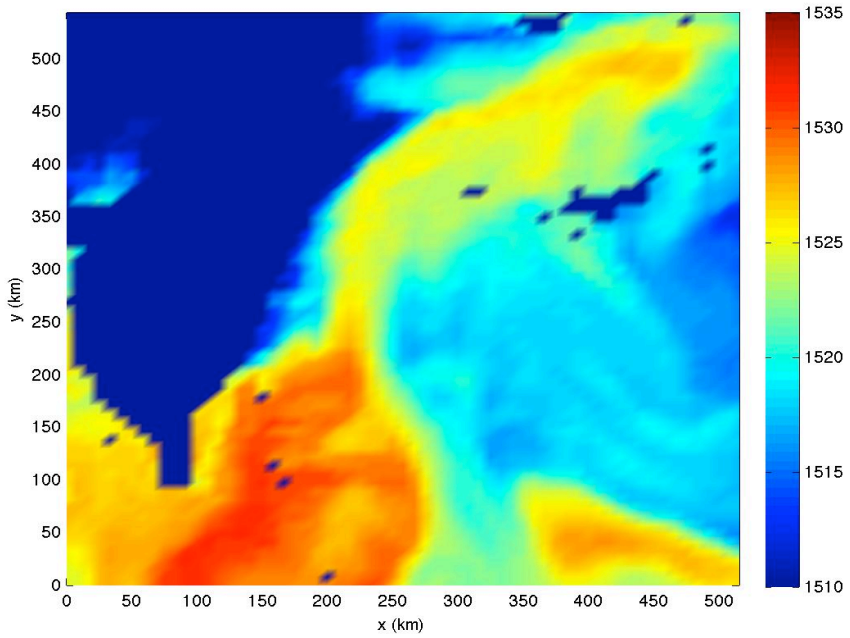

Figure 1: *Sample HyCom oceanographic prediction for the sound speed at a depth of 50 m. Site is east of Taiwan.*

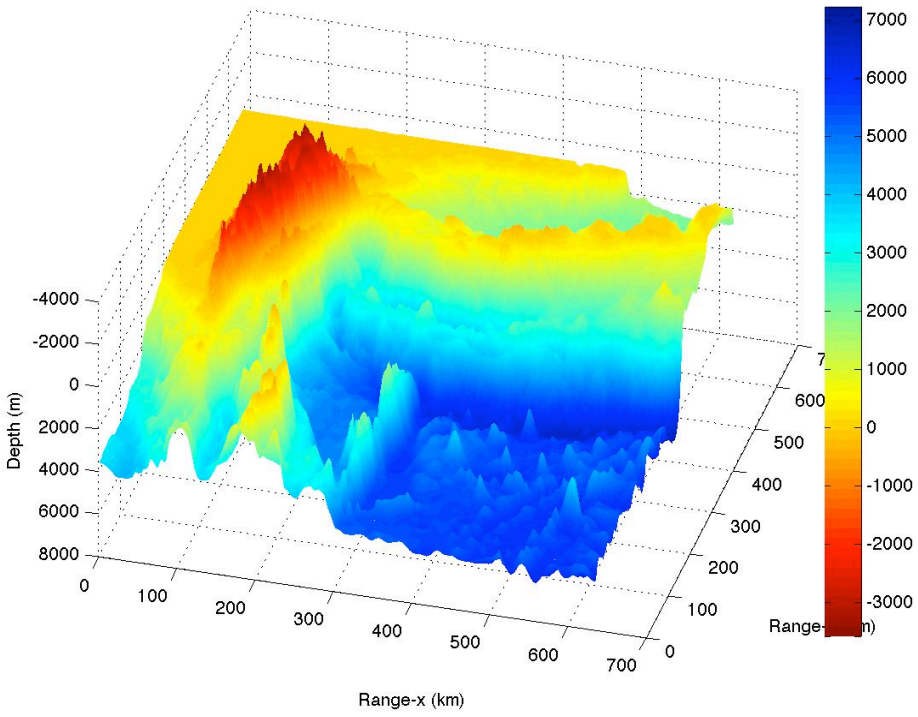

Figure 2: *Bathymetry for the site from the ETOP1 database.*

BELLHOP3D then provides ray traces (Fig. 3) and TL plots (Fig. 4) for cylindrical volumes in the ocean due to a grid of source locations. An obvious question is whether 3D effects matter. Note that some of the sources show significant horizontal refraction and some not. Therefore one may offer the typical scientist's answer: 'It depends'. It depends especially on the application. Bearing errors may be important in back-propagating the received energy to a hypothetical source position. Further, the beam-splitting caused by the *variation* in horizontal refraction radically changes the apparent energy on a bearing-time record (this effect may be important even when the omni-level is not much changed). Finally, we emphasize that the horizontal refraction depends on the source-receiver separation in the sense that the refractive effects often accumulate with propagation distance.

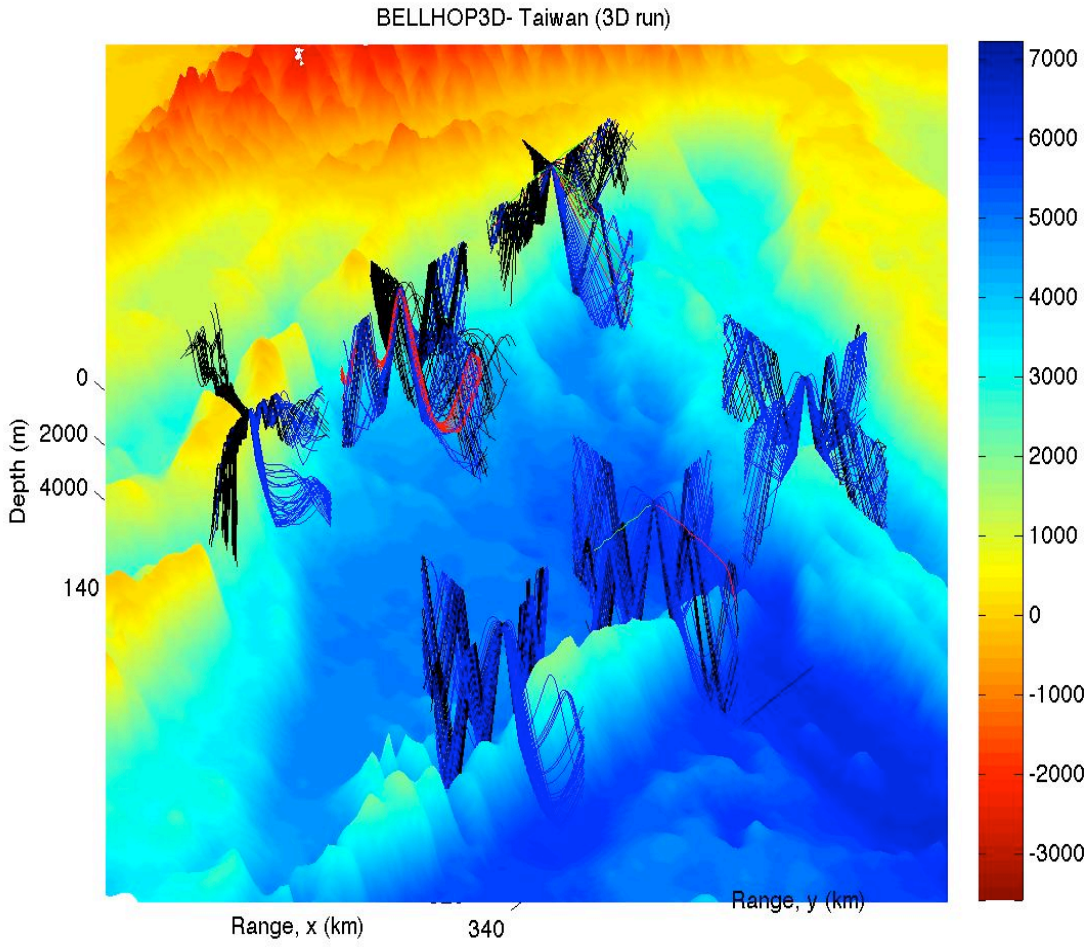

Figure 3: *Ray trace for 6 source locations.*

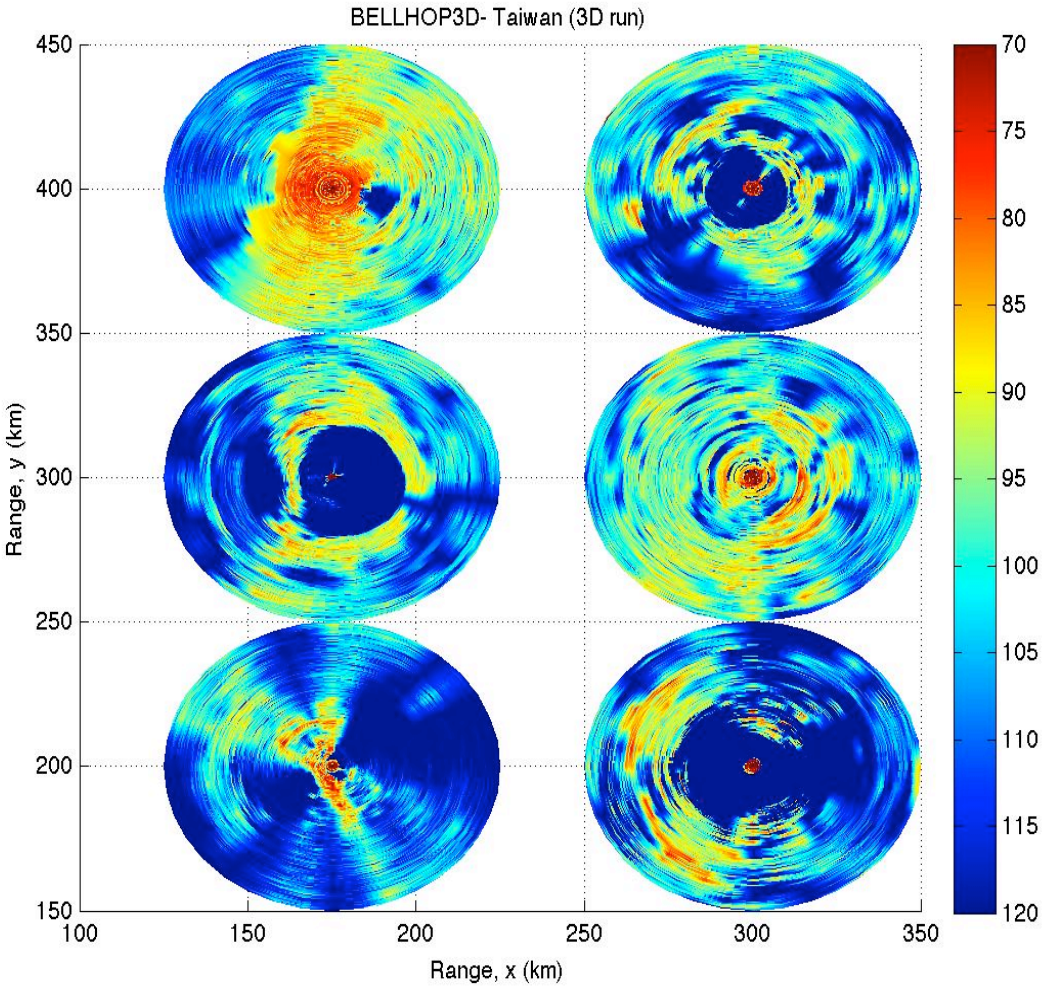

Figure 4: *TL for 6 source locations.*

IMPACT/APPLICATIONS

Three-dimensional effects can be important whenever there is significant variation of the environment in latitude and longitude. Seamounts, canyons, and fjords are examples where the bathymetric variation may be important. Nonlinear internal waves are examples where the oceanography may be important. The limitations of Nx2D models have been recognized for years but we are only now at the point where we have both the environmental information to feed the acoustic models and the computational power to run them.

RELATED PROJECTS

Much of the recent BELLHOP3D code development was supported by the Agency for Defense Development, ROK. We have also been working with NATO CMRE to explore 3D data sets.